An exhaustive evaluation of goals and quality involving both agency personnel and outside educators and scientists was accepted as appropriate in connection with the NSF development grants, which were limited to a few science departments. But this practice applied to all colleges and universities and across the entire range of institutional commitment is horrible to contemplate. However, if public funds are provided by formula for the support of private institutions, decisions at the level of purpose, program, and quality that involve expenditures to be charged to the public will be made by faculty, students, administrations, and boards on many campuses. If I am right in my belief that there should be greater responsiveness among colleges and universities to the needs of their regions and greater specialization in their programs, it may be that public funds should be provided to an institution only after a judgment on the suitability of institutional or program objectives has been made at the state or regional level. The problem we must face is how to avoid a damaging erosion of institutional autonomy, while preserving the financial viability and the quality of our institutions, on the one hand, and how to guarantee the appropriate use of public funds, on the other. Above all, in seeking solutions we should work for stability and continuity of support.

All this seems to argue several things. The plight of many of our institutions is so serious that federal funds are desperately needed. If such funds are provided for broad, general support that is not tied to other national goals, then the appropriate device for providing funds would be revenue sharing, with proper safeguards to ensure that the funds are used for the intended purpose and that adequate account is taken of the objectives and the quality of the institutions receiving support. Steps should be taken to require that all federal agencies which rely on research results in any field of learning for the effective performance of their mission (and particularly those agencies concerned with outstanding social problems) manage programs of research project grants. The basic research budget of the NSF must be protected to assure that the level of basic research continues to be adequate for our national purposes.

Over the past 25 years, the scientific estate has prospered and grown. It is a major glory of the intellectual life of this nation. It can live with the changed priorities of national life. As we move into the lean years ahead, scientists must recognize that academic science can flourish only if the academy itself is healthy, and universities and scientists alike must find ways to influence and adjust to the political, organizational, and economic realities of America in transition.

References

1. *Education Amendments of 1972*, Public Law 92-318.
2. U.S. Office of Education, *Projections of Educational Statistics to 1980–1981* (Government Printing Office, Washington, D.C., 1972), p. 86.
3. *New York Times* (13 November 1972), editorial.
4. Carnegie Commission on Higher Education, *Quality and Equality: New Levels of Federal Responsibility for Higher Education* (McGraw-Hill, New York, 1968), p. 1.
5. L. Levin, Statement to Office of Management and Budget, 20 October 1970, mimeographed, p. 2.
6. National Science Foundation, *Impact of Changes in Federal Science Funding Patterns on Academic Institutions 1968–1970* (Government Printing Office, Washington, D.C., 1970).
7. I. L. Bennett, Jr., "Some suggestions for improving the administration of federal programs of support for academic science," mimeographed, New York, N.Y. (September 1969).
8. H. Brooks, in U.S. House of Representatives, Committee on Science and Astronautics, Subcommittee on Science, Research, and Development, *Hearings* (91st Congr., 2nd sess., October 1970), pp. 931–963.
9. E. R. Piore, *ibid.*, pp. 645–646.
10. *Conflicts between the Federal Research Programs and the Nation's Goals for Higher Education* (Government Printing Office, Washington, D.C., 1965), parts 1 and 2.
11. K. Brewster, Jr., *ibid.*, part 2, p. 171.
12. D. Riesman, *ibid.*, p. 391.
13. J. von Neumann, in *The World of Mathematics*, J. R. Newmann, Ed. (Simon and Schuster, New York, 1956), vol. 4, p. 2063.

The Apollo 16 Lunar Samples: Petrographic and Chemical Description

Apollo 16 Preliminary Examination Team

Introduction

More than four-fifths of the surface of the moon consists of a profoundly cratered, irregular surface designated terra or highlands by analogy with the terrestrial continents. These terra regions have much higher albedos than the physiographically lower and much smoother mare regions. The difference in albedo can now be ascribed to a fundamental difference in the chemical and mineralogical character of these two regions. Lunar samples from landing sites in the mare regions and high-resolution photographs taken from lunar orbit have shown that the lunar maria are underlain by extensive lava flows. Isotopic dating of samples from four mare regions (*1*) indicates that mare volcanism covered a time span of 600 million years beginning about 3.7 billion years ago. The intensely cratered character of the terra regions is due to both the greater antiquity of these parts of the moon and the higher flux of incoming objects that hit the moon during its very early history (*2*). In contrast with the mare region, the origin of the underlying material of the terra is not easily inferred from physiographic criteria. The surface manifestations of early plutonic or extrusive igneous activity—if indeed they ever existed—were erased from the terra regions by the intense early bombardment of the lunar surface. There are some portions of the highlands that may be exceptions to this generalization, in particular, large craters such as Ptolemaeus, Hipparchus, Albategnius, and Alphonsus. The regions bounded by these craters are much smoother than the typical densely cratered highlands. It is generally assumed that these regions are physiographic lows that have been filled with younger material by some poorly understood mechanism. On the basis of detailed studies of the physiographic and albedo characteristics of the basin material, it has been suggested (*3*) that

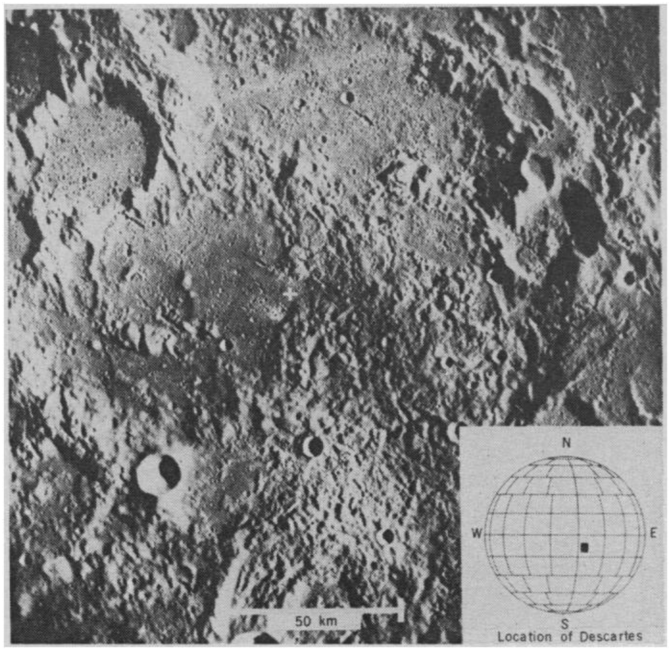


Fig. 1. Metric camera picture of the region around the Apollo 16 landing site, at 9°S, 15.5°E (white cross). The inset shows the approximate location of this region on the front face of the moon. The region receives its name from the very old crater Descartes centered around the scale bar in the lower portion of the photograph.

the filling of the highland basins was a result of volcanic processes similar to those which filled the large mare basins. Some highland basin areas also contain hilly, hummocky regions that bear no relation to large crater rims or crater ejecta. Theses regions have been interpreted as extrusive igneous features formed by viscous, silicic, igneous liquids (*3*).

The elucidation of the origin of both the filled basins and the hilly volcanic regions was the major objective of the Apollo 16 mission. Both types of landforms are remarkably common in the eastern equatorial portion of the southern highlands, facing the earth (Fig. 1). Basin-filling deposits, designated Cayley formation (*4*), and irregular, hilly topography, designated Descartes formation (*4*), occur there in close proximity.

The analysis of high-resolution photographs obtained during the Apollo 14 mission showed that a relatively smooth region 60 kilometers north of the old crater Descartes could provide a landing point with access to both landform types (8°59′29″S, 15°30′52″E). In addition, two very young, bright-rayed craters were relatively accessible from this landing point. The age and mode of formation of these craters is of great interest, but much more important is the fact that the ejecta from these craters provides samples from material that is well below the regolith or gardened surface.

The Apollo 16 lunar module (LM) spacecraft landed successfully within less than 100 meters of the planned landing point. Three traverses extending over a region approximately 8.8 km long and 2 km wide were accomplished. Rock and soil samples were collected from ten different stations within this region. These samples include several specimens from boulders ranging to several tens of meters in size. At five of the sampling stations, rocks that are unambiguously ejecta from nearby craters were obtained. These ejecta blocks and associated soil were sampled in particular detail in order that a more detailed study could be made of the interaction of the lunar surface with both solar and galactic particles (*5*). In this article we summarize the chemical and petrographic characteristics of a representative suite of the Apollo 16 rock and soil specimens. At the present time no clear-cut correlation of any of the observed characteristics with position in the site has been observed. This generalization is based on a detailed examination of only a portion of the returned samples.

Chemical Characteristics

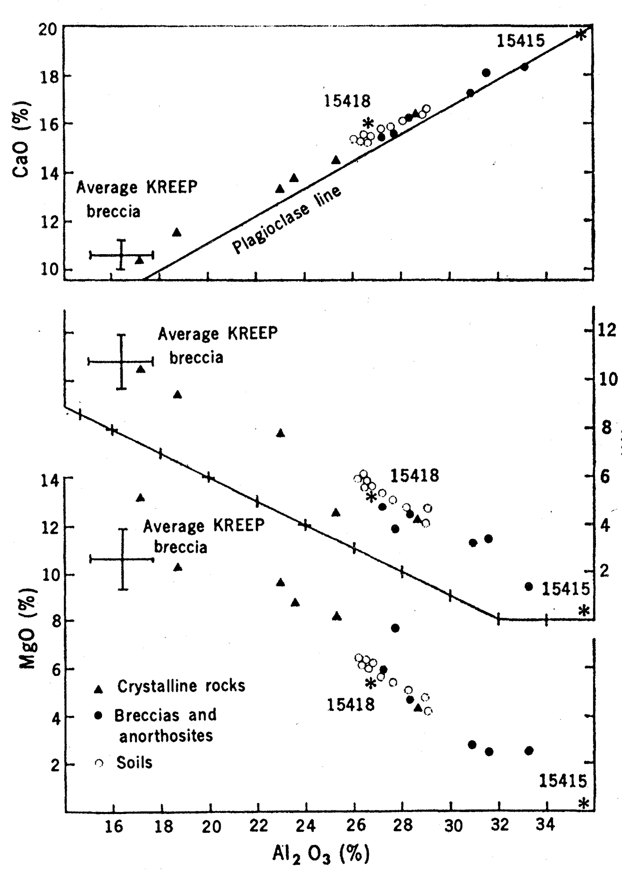
The chemical characteristics of the Apollo 16 rocks are relatively simple and straightforward. The dominant chemical feature is the high abundance of aluminum and calcium. In a number of rocks, the absolute and relative abundances of these elements approach those of pure calcic plagioclase to a very good first approximation. The aluminum content of the rocks is directly correlated with the abundance of plagioclase, which dominates most of the rocks. Except for silicon, most of the rock-forming elements are either strongly concentrated in or excluded from plagioclase. Thus, the abundance of virtually all elements except silicon is strongly correlated with the Al_2O_3 content in the Apollo 16 rocks. The concentrations of all the major elements and several trace elements for 12 rock samples and 11 soil samples are summarized in Tables 1 and 2, respectively. The correlation with the Al_2O_3 abundance for CaO, MgO, FeO, TiO_2, and K_2O is illustrated in Figs. 2 and 3. The data in these figures show that three groups can be defined from the Al_2O_3 content alone. The first group approach pure plagioclase in composition, and they are designated here as cataclastic anorthosites. The second group—consisting of several complex breccias, one crystalline rock, and all soil samples—have Al_2O_3 contents between 26 and 29 percent. The third group have less than 26 percent Al_2O_3 and consist of rocks that are of metamorphosed igneous origin. They can be subdivided into one group having around 18 percent Al_2O_3, with bulk compositions similar to those of the KREEP basalts found at the Apollo 12, Apollo 14, and Apollo 15 sites (*6*), along with a second, more aluminum-rich group with no well-defined counterpart at other sites. The KREEP basalt type (samples 62235 and 60315) is the only rock composition from the Apollo 16 site whose major elemental abundances correspond to those of liquids known to have been produced by partial melting of the lunar or terrestrial interior.

The membership of the Preliminary Examination Team is as follows. The steering group are P. W. Gast, W. C. Phinney, M. B. Duke, E. D. Jackson (U.S. Geological Survey, Menlo Park, California), N. J. Hubbard, P. Butler, and R. B. Laughon. The mineralogy and petrology group are S. O. Agrell (University of Cambridge, England), M. N. Bass (Lunar Science Institute, Houston, Texas), R. Brett, W. D. Carrier, U. S. Clanton, A. L. Eaton (Brown & Root-Northrop, Houston), J. Head (Bellcomm, Inc., Washington, D.C.), G. H. Heiken, F. Horz, G. E. Lofgren, D. S. McKay, D. A. Morrison, W. R. Muehlberger (USGS), J. S. Nagle (BRN), A. M. Reid, W. I. Ridley, C. Simonds (LSI), D. Stuart-Alexander, J. L. Warner, R. J. Williams, and H. Wilshire (USGS). The chemical analysis group are B. M. Bansal, J. A. Brannon, A. M. Landry, J. M. Rhodes, K. V. Rodgers, and J. E. Wainwright (Lockheed Electronics Company, Houston). The low-level counting group are L. Bennett, R. S. Clark, J. E. Keith, G. D. O'Kelley (Oak Ridge National Laboratory, Tennessee), R. W. Perkins, L. A. Rancitelli (Battelle Pacific Northwest Laboratory, Richland, Washington), W. R. Portenier, M. K. Robbins (BRN), and E. Schonfeld. The carbon analysis group are E. K. Gibson, C. F. Lewis, C. B. Moore (Arizona State University, Tempe), and D. R. Moore (BRN). Those members listed with no institutions are from the NASA Manned Spacecraft Center, Houston.

The rather narrow range of soil compositions found at this site is remarkable when compared to those from other sites. In spite of the small range of compositions, all elements in the soils (with the possible exception of strontium and nickel) form well-defined correlations with each other. The simplicity of these correlations suggests that two end members or components prevail in these soils. They are a feldspar-rich material, perhaps similar to sample 67075, and the more ferromagnesium-rich KREEP basalt. Both the relatively low TiO_2 abundance and

Table 1. X-ray fluorescence analyses of Apollo 16 rocks. Abbreviations used: Sta., station; meta, metamorphic; ign., igneous; brec., breccia; anorth., anorthosite; %, percentage by weight; ppm, parts per million; N.D., not detected.

Component	Location, rock type, and sample number											
	Crystalline rocks						Breccias and cataclastic rocks					
	LM site meta. (III) 60315,3	Sta. 2 meta. (III) 62235,4	LM site meta. (III) 60335,1	Sta. 1 meta. (III) 61156,2	Sta. 6 meta. (III) 66095,5	Sta. 8 ign. (III) 68415,6	Sta. 1 brec. matrix (I) 61295,5	Sta. 8 brec. matrix (IV) 68815,9	Sta. 11 crushed anorth. (II) 67955,8	Sta. 13 brec. clast (II, IV) 63335,1	Sta. 1 crushed anorth. (II) 61016,3	Sta. 11 crushed anorth. (II) 67075,4
SiO_2 (%)	45.61	47.04	46.19	44.65	44.47	45.40	45.19	45.10	45.01	45.20	44.15	44.80
TiO_2 (%)	1.27	1.21	0.58	0.64	0.71	0.32	0.56	0.49	0.27	0.42	0.20	0.09
Al_2O_3 (%)	17.18	18.69	25.27	22.94	23.55	28.63	28.29	27.15	27.68	30.86	33.19	31.54
FeO (%)	10.53	9.45	4.51	7.75	7.16	4.25	4.52	4.75	3.84	3.23	1.40	3.41
MnO (%)	0.12	0.11	0.07	0.12	0.08	0.06	0.06	0.06	0.05	0.04	0.02	0.06
MgO (%)	13.15	10.14	8.14	9.60	8.75	4.38	4.72	5.88	7.69	2.81	2.51	2.42
CaO (%)	10.41	11.52	14.43	13.34	13.69	16.39	16.16	15.45	15.54	17.25	18.30	18.09
Na_2O (%)	0.56	0.48	0.52	0.39	0.42	0.41	0.45	0.42	0.40	0.57	0.34	0.26
K_2O (%)	0.35	0.34	0.23	0.11	0.15	0.06	0.09	0.14	0.05	0.05	0.02	0.01
P_2O_5 (%)	0.45	0.41	0.19	0.22	0.24	0.07	0.10	0.18	0.03	0.03	0.05	0.00
S (%)	0.14	0.11	0.07	0.12	0.12	0.04	0.06	0.06	0.01	0.03	0.01	0.01
Sum	99.77	99.50	100.20	99.88	99.34	100.01	100.20	99.68	100.57	100.49	100.19	100.69
Sr (ppm)	156	165	162	153	159	185	187	175	170	225	179	144
Rb (ppm)	9.8	9.3	6.4	2.5	3.9	2.1	2.3	3.4	0.6	1.2	0.7	0.8
Y (ppm)	142	193	62	64	72	23	33	61	16	11	11	2.5
Th (ppm)	7.2	10.5	3.2	3.8	2.7	2.2	1.0	3.7	1.9	1.4	1.7	N.D.
Zr (ppm)	640	851	281	293	322	98	143	266	59	41	48	2.7
Nb (ppm)	37	49	16	17	18	5.6	8.6	16	4.0	3.1	2.4	N.D.
Ni (ppm)	191	248	77	184	258	49	114	206	108	26	39	N.D.
Cr (ppm)	1460	1370	900	960	1010	710	570	690	750	340	200	420



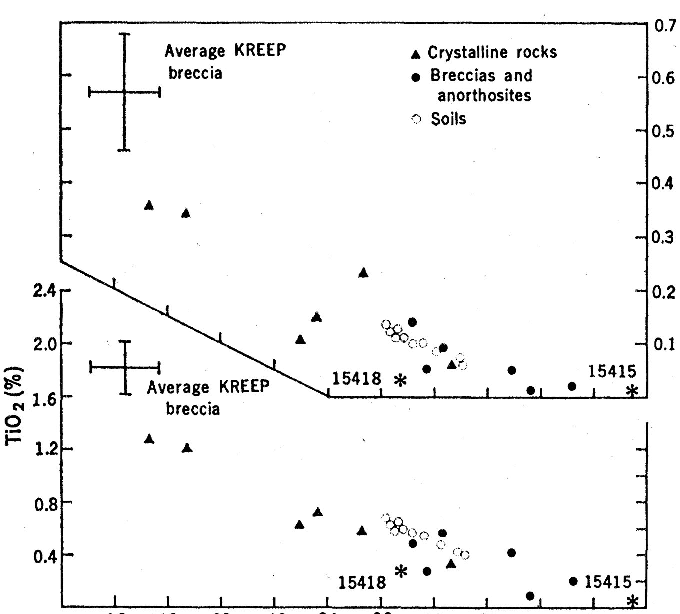
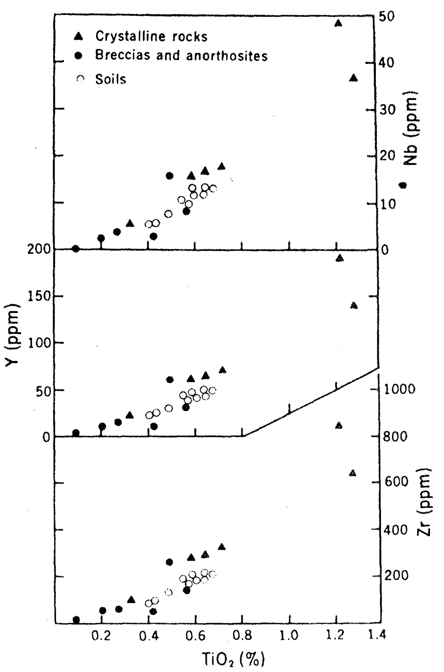


Fig. 2 (left). Correlation of CaO, FeO, and MgO concentrations with the concentration of Al_2O_3 in the Apollo 16 samples. The data for samples 15418 and 15415 are from the Apollo 15 preliminary examination report (*9*), and those for average KREEP breccia are from Hubbard *et al.* (*10*). Fig. 3 (right). Correlation of K_2O and TiO_2 with Al_2O_3 in the Apollo 16 samples. Other data used in this figure are from (*9*) and (*10*).

Fig. 4. Correlation of Nb, Yb, and Zr concentrations with the concentration of TiO_2 in the Apollo 16 samples. Note the nearly identical patterns of data points on these three graphs, indicating a marked correlation between Nb, Y, and Zr.

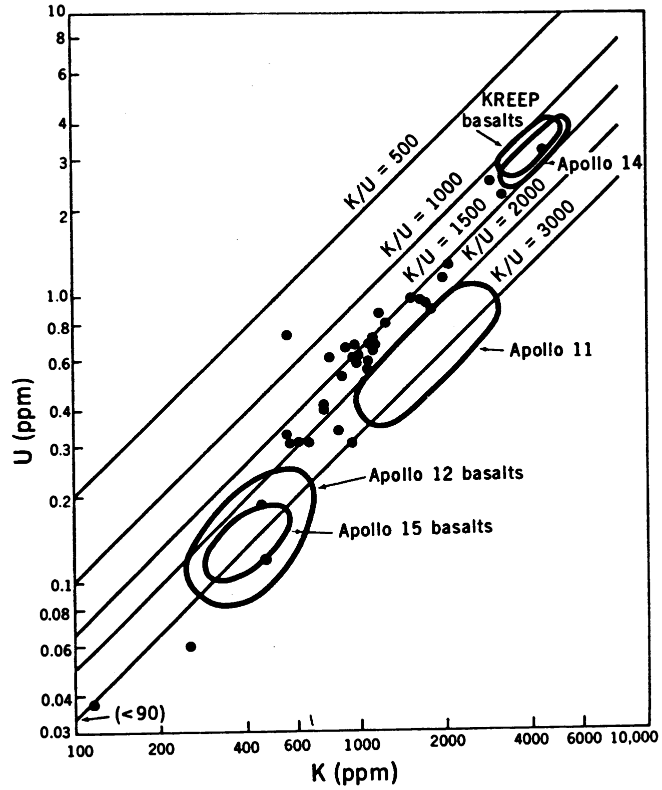


the high Y/Ti and Nb/Ti ratios suggest that the crystalline metaigneous component is relatively rare in the soil. The nickel content of the soils varies by more than a factor of 3. If the nickel abundance is an indicator of a meteoritic component and, thus, a measure of the maturity of the soil, the data suggest that some soils are probably associated with deep ejecta from young craters that have been less gardened than a typical soil from this region. The abundances of niobium, ytterbium, zirconium, and titanium are correlated with each other in both rock and soil samples, the correlation being particularly good within the soil samples. Data for these elements are illustrated in Fig. 4. The four complex breccia samples with Al_2O_3 contents similar to those of the soils have much more variable TiO_2, K_2O, Y, and Nb concentrations than the soils, indicating that they are derived from a more heterogeneous milieu.

Several additional generalizations and comparisons with other lunar materials may be inferred from the strontium, zirconium, ytterbium, niobium, and thorium contents determined for the rocks from this site. Both mare and nonmare basaltic rocks are characterized by relatively high abundances of large quadrivalent and trivalent ions (such as thorium, the lanthanide elements, and zirconium) relative to divalent ions (such as europium and strontium). This characteristic is best illustrated by the commonly observed low abundance of europium relative to samarium and gadolinium. The inverse of this characteristic is observed in pure plagioclase and plagioclase-enriched materials returned from the lunar surface. The ubiquitous fractionation of these groups of elements on the lunar surface indicates that the separation of plagioclase from igneous liquids is common in igneous processes on the moon. The relatively high and relatively constant Sr content of most of the Apollo 16 samples, along with the highly variable and frequently low Zr, Y, Nb, and Th contents, suggests that these samples have been involved in processes where they have become enriched in plagioclase. The Y, Zr, Th, Nb, and Sr contents of samples 60315 and 62235 are distinctly different from those of all other samples and suggest that these rocks are depleted in divalent elements relative to trivalent and quadrivalent elements (that is, they are similar to other lunar basaltic rocks). Their relative abundances are, in fact, similar to those observed for KREEP basalts. The similarity of the trace element characteristics of these two rocks and those of primary magmas supports the conclusion that they represent a relatively undifferentiated magmatic rock. The concentrations of Y, Zr, Th, Nb, and Sr in samples 61156, 66095, and 60335 are intermediate between those found for rocks that are enriched in plagioclase, for example, sample 60016 and the "basaltic" rocks

Table 2. X-ray fluorescence analyses of Apollo 16 soils. Abbreviations used: Sta., station; %, percentage by weight; ppm, parts per million; N.D., not detected.

Component	Location and sample number										
	LM rake soil 60600,2	Sta. 1 sub-surface white soil 61220,2	Sta. 1 upper gray soil 61241,2	Sta. 1 crater rim 61501,1	Sta. 4 trench bottom 64421,1	Sta. 5 rake soil 65701,2	Sta. 6 gray soil 66041,1	Sta. 6 white soil 66081,2	Sta. 11 fillet reference soil 67480,2	Sta. 11 crater rim rake soil 67600,1	Sta. 8 fillet reference soil 68841,2
SiO_2 (%)	45.35	45.35	45.32	44.66	44.88	45.03	45.07	45.38	44.95	45.28	45.08
TiO_2 (%)	0.60	0.49	0.57	0.56	0.55	0.64	0.64	0.67	0.41	0.42	0.59
Al_2O_3 (%)	26.75	28.25	27.15	26.50	27.60	26.47	26.39	26.22	29.01	28.93	26.49
FeO (%)	5.49	4.55	5.33	5.31	5.03	5.87	6.08	5.85	4.66	4.09	5.65
MnO (%)	0.07	0.06	0.07	0.07	0.06	0.08	0.08	0.08	0.06	0.06	0.07
MgO (%)	6.27	5.02	5.75	6.08	5.35	6.02	6.14	6.39	4.20	4.75	6.27
CaO (%)	15.46	16.21	15.69	15.33	15.81	15.29	15.29	15.28	16.54	16.40	15.30
Na_2O (%)	0.38	0.42	0.55	0.41	0.39	0.41	0.38	0.39	0.42	0.44	0.41
K_2O (%)	0.11	0.09	0.10	0.11	0.10	0.12	0.12	0.13	0.06	0.07	0.11
P_2O_5 (%)	0.13	0.10	0.13	0.11	0.13	0.13	0.15	0.13	0.13	0.06	0.12
S (%)	0.07	0.06	0.07	0.08	0.07	0.09	0.09	0.09	0.03	0.04	0.08
Sum	100.68	100.60	100.73	99.22	99.97	100.15	100.43	100.61	100.47	100.54	100.17
Sr (ppm)	173	182	175	167	172	173	167	170	188	194	169
Rb (ppm)	2.9	2.4	2.7	3.0	2.9	2.9	3.0	3.1	1.4	1.3	3.1
Y (ppm)	43	31	37	40	42	48	44	48	22	22	46
Th (ppm)	1.9	2.6	1.2	2.2	2.8	1.9	2.6	3.2	N.D.	1.6	2.4
Zr (ppm)	186	131	162	177	183	207	197	205	86	89	201
Nb (ppm)	12	7.6	9.8	11	11	13	12	13	5.4	5.4	13
Ni (ppm)	293	109	220	256	316	356	362	342	176	111	296
Cr (ppm)	770	590	720	760	710	820	820	830	520	540	780



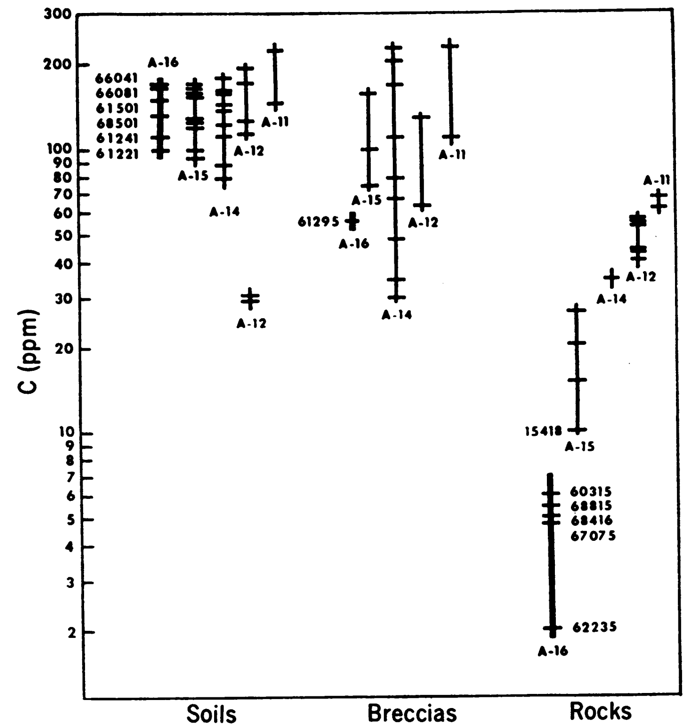


Fig. 5 (left). Uranium plotted against potassium concentration for the Apollo 16 samples, as compared to the general range of samples from previous missions. The data are from NASA Manned Spacecraft Center, Oak Ridge National Laboratory, and Battelle Laboratories. Fig. 6 (right). Comparison of the total carbon abundances for the Apollo 16 sample types with those of samples from previous Apollo missions. The latter data are taken from the Apollo 12, Apollo 14, and Apollo 15 Preliminary Examination Team reports (*9*, *11*) and Moore *et al.* (*12*).

60315 and 62235. Neither the trace element concentrations nor the major element compositions of these rocks excludes the possibility that they are derived from an undifferentiated, highly aluminous parent magma. This possibility is particularly interesting because it suggests that rocks representing the parent liquids for anorthosites may occur at this site. With the exception mentioned above, the chemistry of the Apollo 16 rocks can be accounted for by a rather simple geologic model consisting of a large, igneous complex that is variably enriched in plagioclase and intruded by a liquid rich in trace elements after its formation.

The abundances of potassium, uranium, thorium, and short-lived radioactive elements have been determined for 43 rock and soil samples. These data show that the Th/U ratio of highland materials, like that of most mare samples, is similar to that of chondrites. The K/U ratios of all but two samples from this site fall within the range 1000 to 2000. These data are compared with the potassium and uranium contents of rocks from previous landing sites in Fig. 5. Even though the rocks and soils from the Apollo 16 highland site are relatively low in

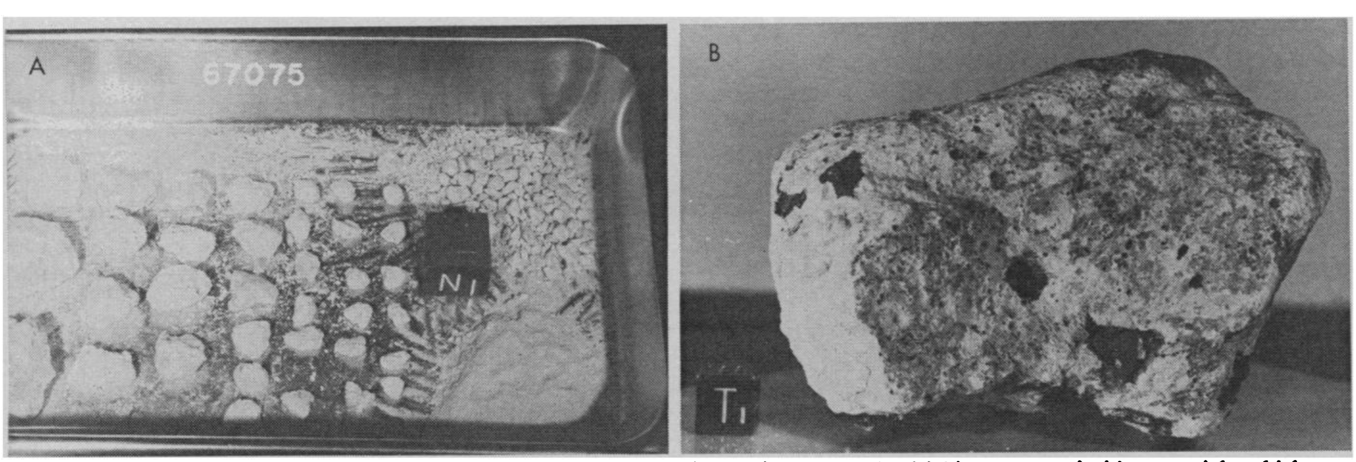
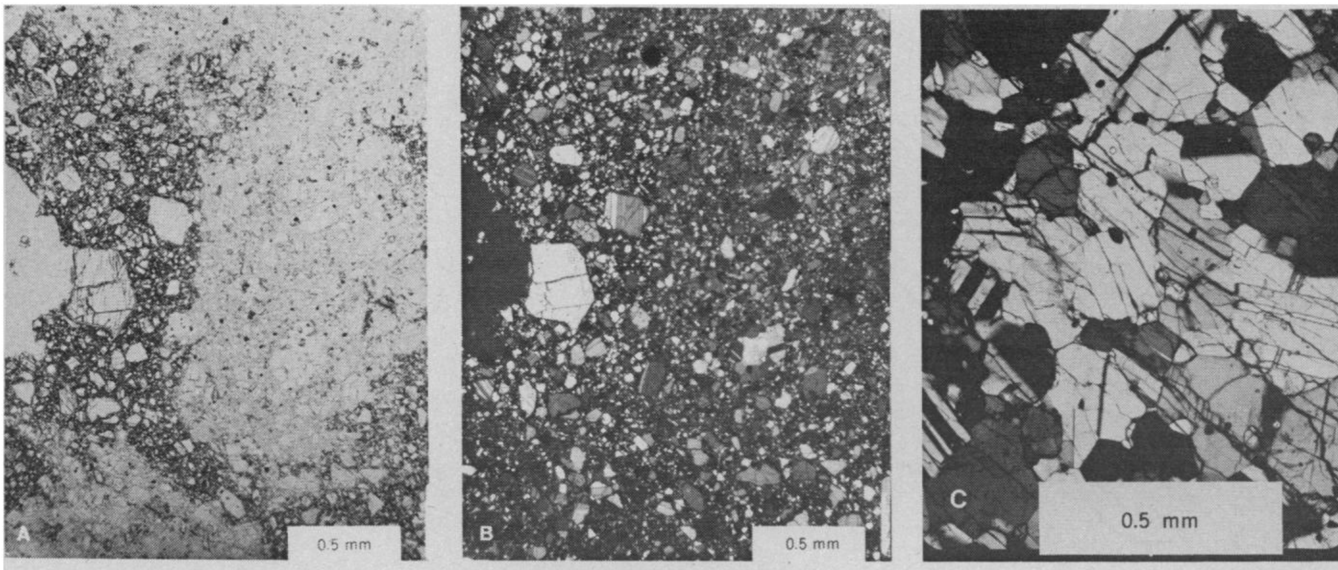


Fig. 7. Typical examples of type II rocks. (A) Sample 67075 shows the extremely friable nature of this material, which was collected as a single rock on the lunar surface. The cube shown is 1 cm on an edge. (B) Sample 65315 is a more coherent but still friable rock of crushed plagioclase. Note the preserved glass-lined impact pits on the "weathered" surface. A few remnants of a black glass coating remain.



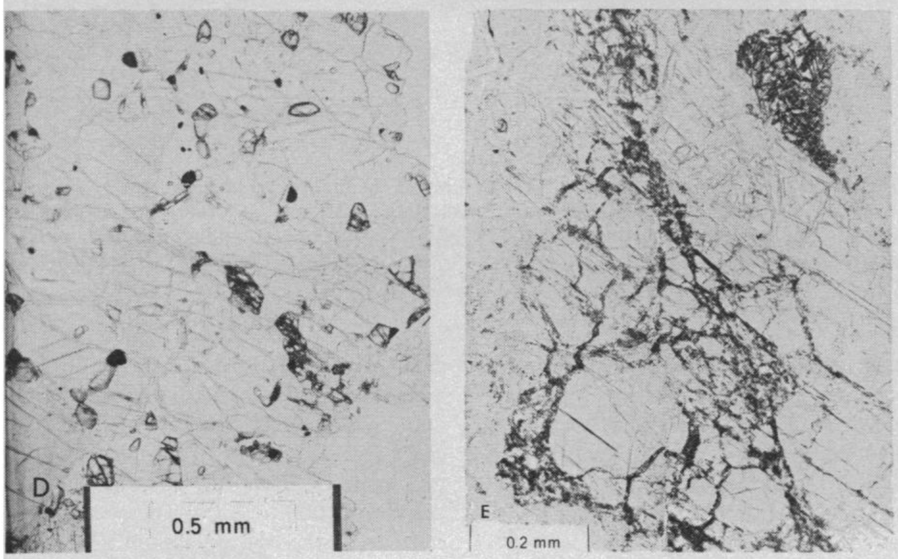


Fig. 8. Thin sections of crushed anorthosites. (A) Section of 67075 (plane light), showing the flowage of gray, crushed material between two lighter zones of crushed material. (B) The same area (crossed polars), showing the recognizable clasts to be primarily plagioclase. (C) Section of 67075 (crossed polars), showing the annealed texture of some grains. Note the typical 120° triple junctions, which are displayed in the upper right. (D) View of same area (plane light), showing the small percentage of mafic silicates, which stand out in higher relief. (E) Patch of diabasic to subophitic intergrowth of plagioclase needles and pyroxene (upper right) with a small projection of similar finer-grained material at its lower end. Similar fine-grained material occurs around the margin and in the fractures of the large, crushed plagioclase grain which makes up the remainder of the photomicrograph.

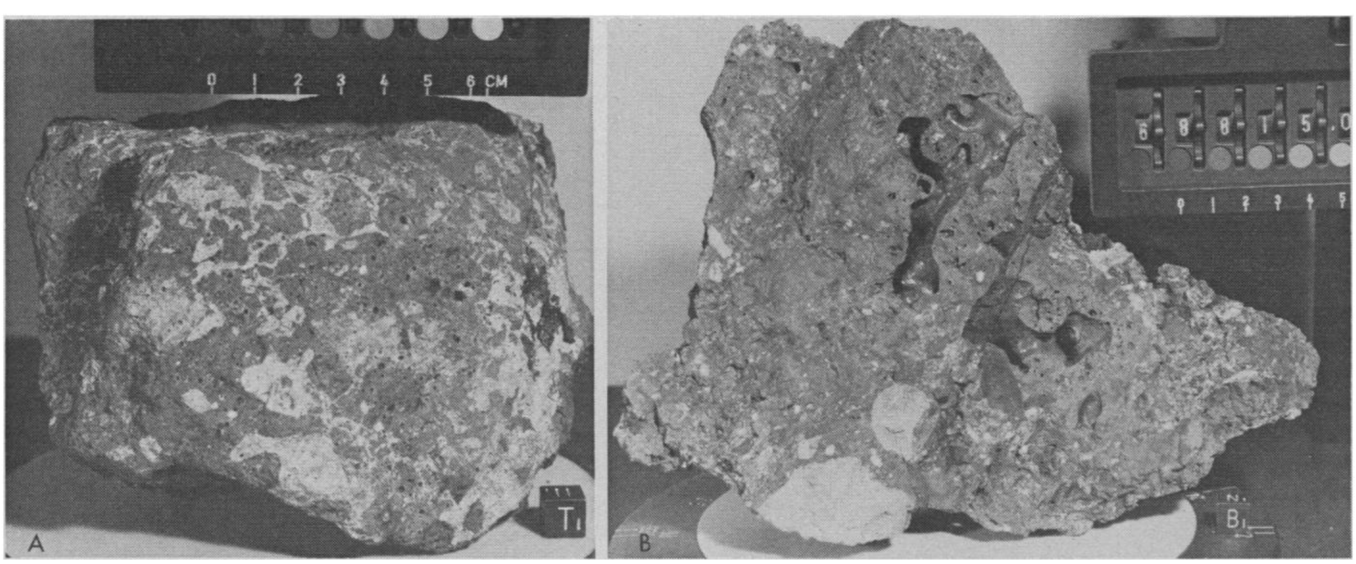


Fig. 9. Complex gray and white breccias. (A) Rock 61015 shows the complex arrangements in which some areas show white clasts in a gray matrix, but others have gray clasts in a white matrix. (B) Rock 68815 shows the predominantly gray version of this rock type. Note the striking tubular vesicles, which indicate the once fluid nature of this rock. Smaller vesicles are concentrated along margins of tubes.

potassium, they have similar K/U ratios to the KREEP basalts and distinctly lower K/U ratios than most mare basalts. These data are in accord with the suggestion that the older and shallower parts of the moon have lower K/U ratios than the deeper interior, which presumably produced the mare basalts.

The carbon contents of 12 soil and rock samples are given in Fig. 6, along with data from previous sites. The soil samples from the Apollo 16 regolith have carbon contents similar to those of most lunar soils. In contrast, the rock samples have carbon contents no more than one-half those of most mare basalts. This difference may be due to (i) a very low carbon content of highland, crustal materials, or (ii) extensive degassing of all samples during their formation. The latter explanation is quite unlikely for the cataclastic anorthosites, which show only minimal evidence of thermal metamorphism. We conclude therefore, that many of the highland rocks are derived from a source rock with a distinctly lower carbon content than most mare basalts. These additional data on the carbon regime of the lunar surface further support the hypothesis that the bulk of the carbon found on the lunar surface originates from the solar wind.

Petrographic Characteristics

Both visual and microscopic examinations show that the coherent rocks from the Apollo 16 site are highly variable in character and complex in origin. Most have macroscopic and microscopic textures that result from two or more events in their history. Cataclastic, highly crushed rocks are common, in addition to complex intergrowths of shock-produced glass, devitrified glass, and preexisting clasts. Other rocks seem to be the product of simple thermal recrystallization, with textures resembling those near large, igneous intrusions. None of the rocks have the hallmarks of lavas or hypabyssal rocks that were so evident in the Apollo 11, Apollo 12, and Apollo 15 mare basalts. To date, petrographic studies of Apollo 16 rocks have uncovered only two or possibly three specimens that can be unambiguously categorized as holocrystalline, igneous rocks. The scarcity of such rocks at this site is well illustrated by the astronauts' descriptions while they were on the surface. Astronaut Duke commented while driving to station 1 during the first extravehicular activity, "I haven't seen any [rock] that I'm convinced is not a breccia."

In the preliminary examination all the rock samples, including several hundred fragments collected with a raking tool, were cleaned to remove dust coatings from their surfaces. The surfaces were then examined visually and with a low-power binocular microscope. In addition, petrographic thin sections of 35 specimens were studied by conventional petrographic methods. Four rather broadly defined rock types can be identified from this examination:

1) Cataclastic anorthosites (type II) (7).

2) Partially molten breccias (type IV).

3) Igneous and high-grade metamorphic rocks (type III).

4) Polymict breccias (type I).

Cataclastic Anorthosites (Type II)

This type consists of white, generally friable, highly brecciated, anorthositic rocks. Degrees of coherence in this group vary; some samples, during transit and handling, have broken into many fragments (Fig. 6A), while others have remained as single fragments (Fig. 7B). Examined under the binocular microscope, these rocks appear to consist of 70 percent (or more) plagioclase in the form of clear, gray, or white grains (generally all three types occur in each specimen), and a few light yellow to honey brown to light green minerals. Most of the rocks have partial to nearly complete dark gray, vesicular, glass coatings, much of which has been lost through micrometeorite erosion. Observations of thin sections confirm a very high plagioclase content with pyroxene and olivine in highly crushed or annealed textures that suggest cataclastic deformation of anorthositic fragments. A question that needs to be answered for this category is: Are all of these rocks cataclastically deformed fragments, or are some detrital in origin? Differing degrees of coherence and relations of different types of plagioclase grains may be associated with differing degrees of shock and may be geographically distributed in a meaningful way. Our first impression is that the most friable and least coherent white rocks were collected at the rim of North Ray crater.

The extremely crushed nature of the plagioclase in thin section is illustrated in Fig. 8, A and B. In Fig. 8A, it appears that the crushed material of the darker area was behaving as a fluid and was squeezed between the two lighter areas. The somewhat annealed nature of the crushed plagioclase is seen in Fig. 8C, where some of the grains meet at triple junctions. The small percentage of mafic silicates is shown in Fig. 8D. Indications of partial melting are present in this rock type. Small patches with diabasic to subophitic textures occur interstitially to some plagioclase grains. Small veinlets of finer grain size occur sporadically as offshoots from these patches. Similar veins often occur along parts of the margins of plagioclase grains, or as veins in them (Fig. 8E). Apparently, the white, clear, and gray areas seen under the binocular microscope represent partly crushed plagioclase, diaplectic glass, and partially melted zones, respectively. Some specimens of this type of rock contain a somewhat higher percentage of mafic silicates, but are still in the range of anorthositic rocks (more than 70 percent plagioclase). For example, samples 67955, 64435, and 60025 have at least 10 percent olivine as subhedral grains, both as small inclusions in plagioclase and as larger grains in pyroxene, which is interstitial to plagioclase. These rocks are highly crushed, but thin sections display a few areas in which the original texture is preserved. They were probably troctolitic anorthosites.

Some special problems are posed by these cataclastic rocks. There is evidence that they retain relicts of a much coarser-grained fabric. The relicts suggest that, although the grains are intensely crushed, the rocks were not necessarily highly stirred and may retain discernible preshock textures. The relicts are generally most evident in plagioclase, but they can also be seen in mafic minerals. For instance, in sample 60025 the orthopyroxene is generally much coarser than olivine and of a size comparable to the largest plagioclase relicts. The olivine grains can be arranged in a series in which progressive polygonalization and rotation of small blocks is seen. The series suggests that the original average grain size of olivine was at least as large as the largest mildly polygonalized grains and was probably comparable to that of orthopyroxene. Such grain sizes and shapes are a clue to the preshock nature of the rocks, which may be parts of the original lunar crust.

In 67955, a clearly discernible relict cumulus texture is evident in the form of extensive orthopyroxene oikocrysts, which enclose ovoid olivine and plagioclase. Early ovoidal olivine, without an orthopyroxene mantle, is enclosed in plagioclase. The whole specimen (as judged from a view of the thin section under low magnification) appears to have a lamination which may be relict layering; like the relicts of coarse-grained texture, this indicates that this rock and probably others were not necessarily highly stirred when they were shocked.

Partially Molten Breccias (Type IV)

This type consists of a rather complex series of breccias containing white and gray material. In some cases it appears that the white material is matrix that contains gray clasts, while in other cases it appears that the gray material is matrix that contains white clasts. In many instances, these two cases occur in the same rock (Fig. 9A). The proportions of white and gray material vary considerably from one specimen to another. For example, samples 68815 and 60017 consist primarily of the dark material, but show a few small spots of white (Fig. 9B). These two rocks also contain long, worm-like, tubular vesicles. In 68815 there is a higher proportion of white material, which occurs for the most part as distinct clasts in the dark matrix, but other portions of this same rock have larger white areas in which a few gray fragments occur. A frothy, vesiculated zone also occurs on one side of this rock.

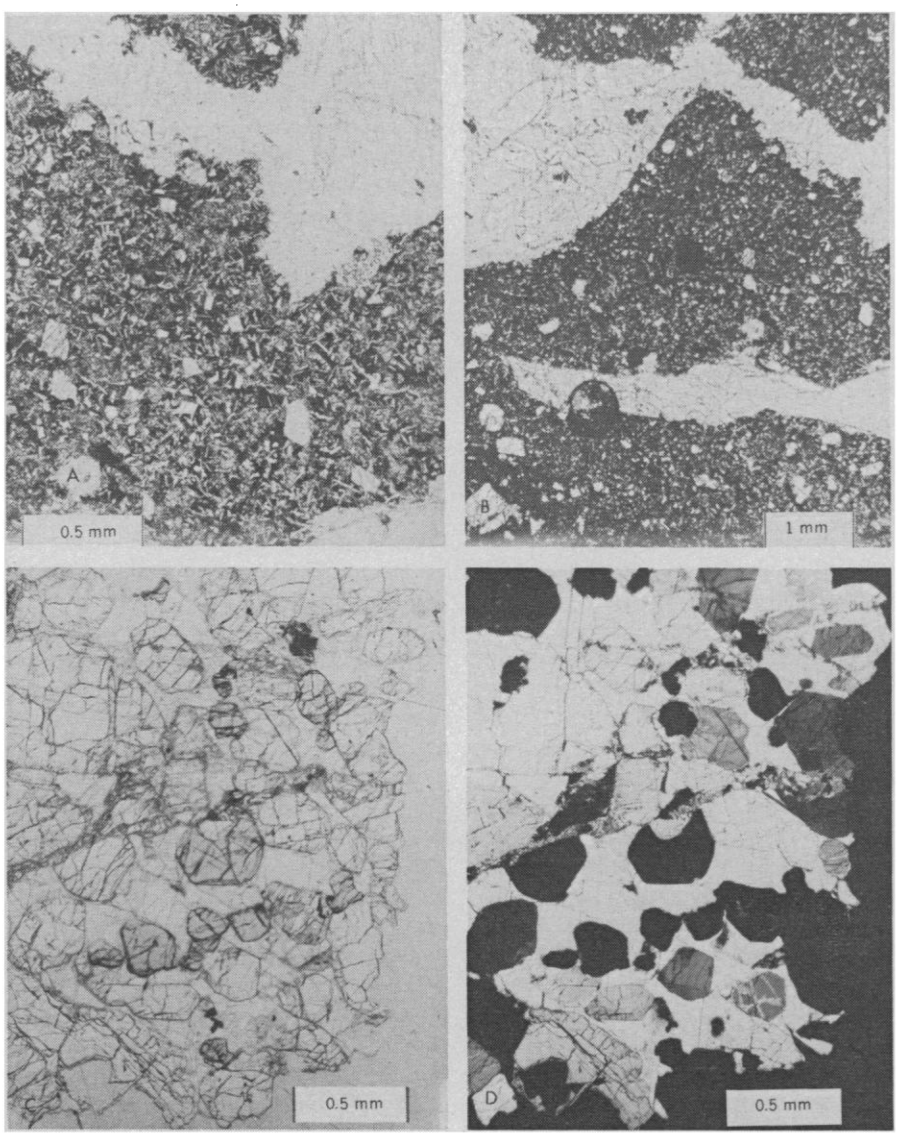


Fig. 10. Complex gray and white breccia. (A) Sample 61015 (plane light), view of a white vein through a gray area. Plagioclase occurs in the gray material as both small needles and larger, rounded to angular fragments (see text). (B) View of a larger area of the same section showing the vein-like nature of the white crushed plagioclase. (C) Clast from 67435 (plane light), view of plagioclase (very light gray), subhedral olivine (light gray), and spinel (gray). (D) View (crossed polars) to illustrate the isotropic nature of the spinel and the poikilitic nature of the plagioclase.

The dark material is aphanitic and, under the binocular microscope, is suggestive of devitrified glass. Thin sections confirm this but also show varying amounts of mineral debris as well as small, fine-grained, gray clasts included in the flow-banded devitrified glass. In some areas, the gray material consists of many rounded to angular fragments of plagioclase in a finer-grained matrix containing many needles of plagioclase randomly arranged as though crystallized from a melt (Fig. 10A). The rather ragged edge of the large white plagioclase area in contact with the small needle-bearing matrix, the small islands of plagioclase that seem to have been wedged off the lower edge of the plagioclase arm (Fig. 10A, upper left), and the small dike-like embayment on the upper edge of the arm all lead to the conclusion that the gray material was, at one time, in large part melted. It is similar in composition to anorthositic rocks (Table 1). The white material, anorthositic in composition, is in various stages of brecciation or recrystallization.

It seems clear that there is a heterogeneous set of gray and white, partially melted rocks that are found throughout the landing site. Perhaps these rocks are part of a series in which varying degrees of melting and assimilation of clasts and fine debris have occurred. The white clasts may have been granulated to the point where they behaved mechanically as a fluid and were squeezed into the partially melted matrix as veins and blebs, which may, in turn, have picked up a few fragments of the dark material (Fig. 10B). Some of the white clasts have not been significantly deformed and contain textures that probably reflect a previous environment. One of these in rock 67434 contains subhedral olivine and pink spinel in a poikilitic plagioclase matrix (Fig. 10, C and D). It should be noted that many of the olivines in the Apollo 16 rocks have unusually low interference colors and are difficult to distinguish from orthopyroxene.

Igneous and High-Grade Metamorphic Rocks (Type III)

This type includes a variety of homogeneous, coherent, crystalline rocks. The greatest variation in chemical composition of the Apollo 16 rocks occurs in this group. Again, there is a general predominance of plagioclase, which seems to be present in quantities that normally range upward from about 70 percent, although in some instances the percentage of mafic minerals is significantly greater and in two of the rake samples (67667 and 64815) approaches that of an ultramafic rock. The grain size is generally of the order of a millimeter or less. In some rocks (such as 68415, 68416, and 65015) the plagioclase is euhedral, while in others (such as 61156 and 65095) it is anhedral. Light green or yellow to honey brown mafic materials are seen in most of this group under the binocular microscope. Examinations of thin sections of this type indicate that there are two major subgroups. One subgroup contains euhedral plagioclase laths of various sizes plus pyroxenes and perhaps olivine in a texture indicative of crystallization from a melt. The plagioclase occurs both as well-developed laths in a diabasic texture complete with large phenocrysts (Fig. 11A) and as skeletal crystals that formed during rapid cooling from a melt from which plagioclase, olivine (orthopyroxene?), and spinel (Fig. 11B) crystallize. The other subgroup has large poikilitic pyroxene grains, which include plagioclase and other mafic minerals (Fig. 12, A and B). The poikilitic grains are made up of numerous individual, irregularly shaped areas of pyroxene. The texture is indicative of recrystallization, as in a metamorphic hornfels.

An interesting observation on rock 66095 of the second subgroup is the alteration of numerous areas where the original phases have taken on a rusty appearance. In many instances, the rust penetrates as a stain into the zone around these phases. The rust-like material also forms a very thin crust along some fracture surfaces. Its optical properties in polished thin sections are those of goethite. Although it appears that some of this alteration must have occurred on the lunar surface, it remains to be determined how much of it might result from exposure to the atmospheres of the spacecraft and earth during the return trip.

Polymict Breccias (Type I)

This type consists of polymict breccias with a white to very light gray, moderately friable, clastic matrix, in which material with a grain size of less than a few tenths of a millimeter predominates (Fig. 13). The matrix appears to be a more crushed equivalent of the clast materials and is essentially free of glass. Clasts in these breccias are generally of the order of a few millimeters in size, although rarely there may be clasts a few centimeters across. The clasts range from very white and plagioclase-rich, through various shades of gray, to medium dark gray and aphanitic. The lighter clasts may contain up to 20 or 30 percent mafic minerals, and they range from

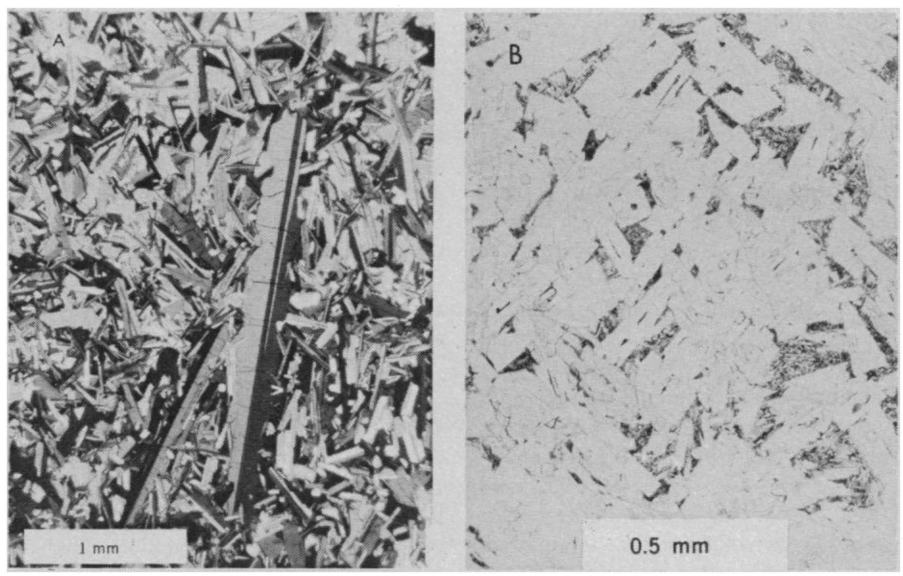


Fig. 11. Igneous crystalline rocks. (A) Sample 68416 (crossed polars), view showing euhedral plagioclase laths both as phenocrysts and in a diabasic matrix, which also contains about 20 percent pyroxene as smaller, irregularly shaped grains between the laths. (B) Sample 62295 (plane light), view showing skeletal plagioclase laths, with interstitial plagioclase and olivine (orthopyroxene?) that formed from a trapped interstitial melt. The mineral seen in higher relief as small, euhedral, inclusions in the large plagioclase grains is spinel.

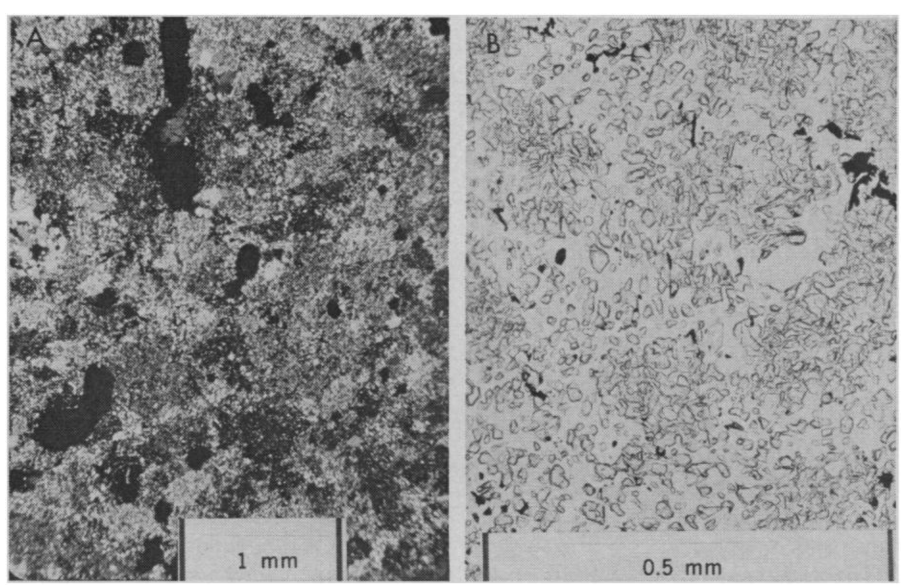


Fig. 12. Poikilitic crystalline rocks. (A) Sample 61156 (crossed polars), view showing irregularly shaped poikilitic patches of pyroxene accented by the different shades of gray. Each of the patches contains numerous individual grains, as shown in the higher magnification in (B), a plane light view of a highly magnified area of one poikilitic crystal.

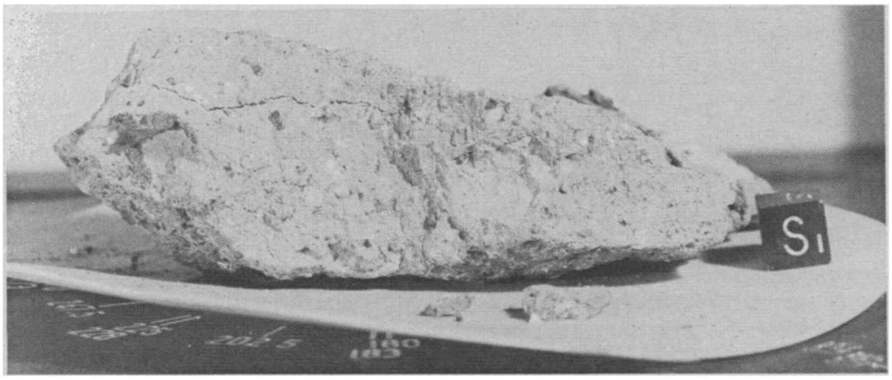


Fig. 13. Typical type I rock, 61295, showing gray and white clasts in a friable, light gray matrix, which is predominant over clasts. Note the fracture which trends subparallel to the top surface. Such fractures are common in this rock type.

anorthositic to gabbroic, noritic, or troctolitic in composition. The darker clasts may be devitrified glass and rarely contain small white spots. The distribution of various clast types appears to vary from sample to sample.

This category is typified by samples 60016, 60019, 61135, 61175, 61295, 66035, and 66075. Other specimens that are similar include 63355, 67015, 67016, and 67115, which are lighter in color, more coherent, and contain predominantly aphanitic dark gray clasts of a larger size. Still other specimens, such as 65786, 65925, and 61525, display a slightly darker color and are somewhat more coherent than the typical type. However, the matrix and variety of small clasts appear to be similar in all subgroups. It may be significant that the lighter-colored subgroup occurs in the northern part of the landing site at stations 11 and 13, while the more typical examples occur farther south.

Thin sections of this type show the matrix to consist entirely of crushed mineral fragments with essentially no glass, even down to a very fine scale. Although there is a variety of clast types, the predominant one is plagioclase, as one would predict from the chemical analysis of sample 61295 (Table 1). The plagioclase clasts exist as large, ragged, single crystals, annealed aggregates, finely crushed material, and some maskelynite (Fig. 14). The various gray, aphanitic clasts seen under the binocular microscope apparently consist of finely crushed plagioclase aggregates or devitrified glass. Finally, there are a few clasts containing poikilitic pyroxene and some consisting of glass.

The clast population of these rocks is, at the present level of examination, similar to those of the other rock types found at this site. Except for the near absence of glass, the characteristics of these rocks, including the moderately high carbon content of one analyzed example of this type, suggest that they are indurated equivalents of local regolith. The variability of the TiO_2 and K contents, in contrast to the smooth trends exhibited by the present surface soils (Fig. 3), suggests that these rocks are derived from a more heterogeneous source than the present regolith.

Glass and Opaque Minerals

In addition to the four rock types listed above, there are several forms of glass; these include two glass spheres, 60095 and 65016, the latter being hollow. Other predominantly glass samples are generally vesicular agglutinates. In addition, we note that both type IV and type II are commonly coated with a dark gray glass. Types I and III do not show such coatings. A thin section of this glass shows a high degree of devitrification, much of which appears to be plagioclase, but the finegrained nature of the crystals makes their identification difficult.

The opaque mineral content of most rocks of types II and IV is generally low compared to that of rocks from other landing sites, ranging from less than 1 percent to less than 0.01 percent. The cataclastic anorthosites contain the lowest opaque mineral content of the four rock types; sample 65315 contains no more than about 0.001 percent opaque minerals. The poikilitic rocks of type III contain the highest contents of ilmenite; it is consistently present in amounts greater than about 2 percent. Rock 63335 contains even greater amounts. The high ilmenite content is a reflection of the relatively high titanium content of this group.

In the Apollo 16 rocks, unlike most rocks from previous missions, metal and troilite commonly predominate over opaque oxide minerals; but generally the metal and troilite contents do not appear to be exceptionally high for lunar breccias. In no rock examined was the metallic iron content greater than about 1 percent. Ilmenite is commonly the dominant oxide mineral. The shapes and sizes of the ilmenite grains provide a useful index for determining the degree of crystallinity of the breccias.

Discussion of Petrography

The textural characteristics suggest that types II and IV may not be clearly distinguishable. They may form a continuous series ranging from crushed anorthositic rocks with little or no partial melting to those with a high degree of melting and crushing. The similarities in mineralogy, clast types, chemical composition, and textural gradations all argue for such a continuous series. Some rocks are nearly all white, crushed anorthosite, and others are nearly all gray, partially melted anorthosite; the entire range of white and gray mixtures between these extremes can be observed. Many of these rocks seem to be cataclastically crushed, preserving relict textures of the original rocks; but others seem to be more highly brecciated and melted, leaving only a few clasts with a clue to the texture of the original rocks. Nevertheless, the clasts are similar to the relict cataclastic textures in their anorthositic affinities, both mineralogically and texturally. Moreover, the textures of the rocks of types II and IV suggest that these rocks are distinct from all other lunar breccias. They contain no evidence that they are mechanically produced mixtures of preexisting rocks. They are monomict rather than polymict breccias in the sense that these terms were used by Wahl (*8*) to describe meteorites. They exhibit peculiar melting textures, perhaps related to macroscopic or submacroscopic heterogeneities. The molten parts, whether they are the major portions of the type IV rocks or small molten portions within the type II rocks, are generally richer in iron and magnesium than the surrounding or enclosed material. We suggest that the heterogeneous occurrence of mixtures with lower melting temperatures determined whether or not particular parts of a rock underwent melting. Thus, the early melting patches in some rocks may, in fact, represent late crystallizing interstitial liquids in a coarse-grained anorthositic cumulate. No chemical analysis was made of the glass coating on types II and IV, but it may well be similar to the anorthositic rocks of groups II and IV and represent the nearly totally melted equivalent of the gray areas in these rocks.

These descriptions of the rocks indicate that rock types II and IV originated from a relatively coarse-grained, igneous complex consisting predominantly of anorthosite, which was directly transformed to the observed rocks by impact or cataclysmic metamorphism. Some of the anorthosite was troctolitic, as indicated by the early euhedral crystallization of olivine in some rocks and clasts. The rare ultramafic rocks among the rake samples may be related to this complex either as small layers or as sparse fragments from a greater depth. Although the original source area for these particular rocks is uncertain, it does not appear to be in the upper few tens of meters beneath the landing site. This conclusion is based on the photographs of North Ray crater, which contains boulders of breccia; the ejecta from North Ray and South Ray craters; and the interpretation of the active seismic experiment data. Nevertheless, the widespread distribution of the series of rock types II and IV over both mountains and plains areas and the similar widespread conformity of the soil composition, which ranges from anorthositic gabbro through gabbroic anorthosite and represents the homogenizing and reworking of many layers of material in the upper few hundred meters of the entire area, suggest that the area is underlain at some depth by an anorthositic complex.

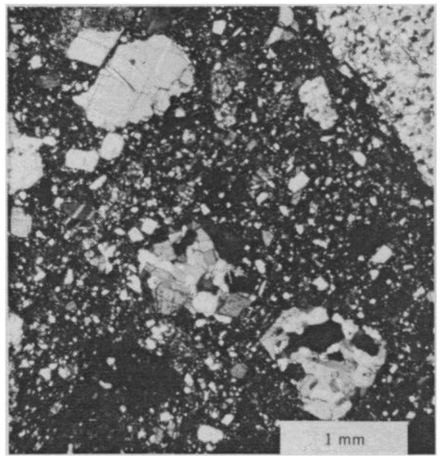


Fig. 14. Thin section of rock 61295 (crossed polars). The clasts show the variety of plagioclase assemblages: finely crushed (upper right); annealed (lower center); large, ragged single crystal (upper left).

The origin of at least some of the type III rocks—in particular, those with KREEP basalt chemistry—may be unrelated to the anorthosites. The igneous rocks 68416 and 68415 are two chips (separated by 20 to 30 cm) from a large boulder. Even though these specimens are from a single rock, they are appreciably different in grain size. The parent rock may represent a portion of a pool of impact molten material rather than an unshocked part of the underlying anorthosite. In this case the two chips are genetically the extreme end members of the type II-IV series.

Reviewing the classification of the Apollo 16 rock specimens in terms of their petrogenesis, we find three major types:

1) A series of cataclastically and cataclysmically modified anorthositic rocks, probably derived from an anorthositic complex which contained from 70 to 90 percent plagioclase.

2) Igneous rocks, at least some of which underwent thermal metamorphism.

3) Polymict breccias that are mechanical mixtures of the preexisting rock types.

None of the returned samples are in accord with the preflight hypotheses concerning the origin of the landform units in this region. The rocks that apparently underlie the regolith of the plains region are in no sense volcanic. No evidence for lava flows or pyroclastic rocks was observed. The only possible rocks that could correspond to the Descartes volcanic unit presumed to underlie the hilly region to the north and southeast of the landing site are the high-alumina, igneous rocks (such as 66095 and 61156) or the KREEP basalts, which have metamorphic textures. The absence of sharp compositional gradients over the surface argues against the latter possibility. The more detailed study of soils and rake samples from stations 5 and 6 should clarify this conjecture.

Table 3. Comparison of the fractions in the size range 62.5 to 125 μm. Values are given as percentages by weight.

Component	Sample number and number of grains								
	61220 (100)	64421 (100)	66041 (105)	66081 (174)	68820 (100)	68841 (100)	69940 (100)	67480 (100)	67600 (100)
Agglutinates	8	54	39	53.4	52	80	64	24	20
Colorless glass fragments	23	3	3.8	9.8	2	2	4		3
Colorless glass droplets	2	1		1.7	1				2
Brown glass fragments				2.9		2	6	3	1
Brown glass droplets		1		1.7	Trace			1	Trace
Orthopyroxene				2.9	2		1	4	
Clinopyroxene	8	1	2.8			3	1	5	3
Plagioclase	35	15	16.1	9.2	15	7	7	22	22
Metamorphosed breccia	12	17	21.9	7.5	21	6	7	15	21
Vitric breccia	10	7	15.2	9.8	1	Trace	7	24	22
Anorthositic					6		2	1	5
Basalt	1	1		0.6		Trace	1		1
Olivine	1								
Ilmenite			0.9						
Potassium feldspar (?)				0.6					

Soil Characteristics

The fractions of 32 soil samples in the size range greater than 1 mm were examined surficially. For nine of these soil samples thin sections of the fraction smaller than 1 mm were further investigated. The fragments observed in these studies can be grouped into (i) glass-coated particles (agglutinates), (ii) mineral or lithic fragments that largely correspond to the rock types mentioned above, and (iii) a variety of vitric fragments. The lithic fragments include the breccias described above and the cataclastic anorthosites. Discrete mineral fragments of plagioclase, clinopyroxene, orthopyroxene, and olivine are relatively common. Trace quantities of pink spinel and potassium feldspar were also found. The prevailing glass type is colorless with a relatively high refractive index. Brown or colored glasses are much rarer at this site than they were at other Apollo landing sites.

The relative abundances of glassy and crystalline fragments are given for nine soil samples in Table 3. The abundance of glass varies rather markedly.

The median grain size of most soil samples ranges from 76 to 112 micrometers. However, the two samples from North Ray crater (67480 and 67600) and one whitish soil from station 1 (61220) are much coarser; their median grain size ranges from 250 to 300 μm.

It is noteworthy that the three coarser soils all have relatively low abundances of agglutinates as well as relatively low nickel contents. The concurrence of these three parameters suggests that these soils have been subject to gardening for a much shorter time than the typical soil. The occurrence of an immature soil (61220) in the bottom of the trench at station 1 suggests that remnants of relatively young rays from North Ray crater may be overlain by mature soils ejected from small, shallow craters. If this interpretation of the North Ray soils is accepted, they are clearly distinguishable from soil interpreted as South Ray ejecta which contains dark brown to black, vesicular glass droplets and dark gray breccias.

The core samples collected during the mission are summarized by Hörz *et al.* (*5*). Of particular note are the three sets of cores taken within 100 m of each other in the area of the LM and the Apollo lunar surface experiments package (ALSEP). The x-radiographs of the cores indicate that some correlations are possible between them, which will enable us to make the most detailed reconstruction of the lunar soil strata to date. The nature of the Descartes material may be classified by the core at station 4. Because of the ubiquitous covering of South Ray ejecta on Stone Mountain, the sampling of Descartes material on the surface is difficult. The x-radiographs of the station 4 material indicate a distinct change in grain size, abundance of rock fragments, and rock types at a depth of about 51 cm. It is possible that the underlying 20 cm of soil may contain evidence of any differences in chemical or mineralogical components in the Descartes material.

Summary

The preliminary characterization of the rocks and soils returned from the Apollo 16 site has substantiated the inference that the lunar terra are commonly underlain by plagioclase-rich or anorthositic rocks. No evidence has been found for volcanic rocks underlying the regolith in the Apollo 16 region. In their place, we have found anorthositic rocks that are thoroughly modified by crushing and partial melting. The textural and chemical variations in these rocks provide some evidence for the existence of anorthositic complexes that have differentiated on a scale of tens to hundreds of meters.

The occurrence of deep-seated or plutonic rocks in place of volcanic or pyroclastic materials at this site suggests that the inference from physiographic evidence that the latter materials are widespread in terra regions may be incorrect.

Several additional, more specific conclusions derived from this preliminary examination are:

1) The combination of data from the Descartes region with data from the orbital x-ray fluorescence experiment indicates that some backside, highland regions are underlain by materials that consist of more than 80 percent plagioclase.

2) The soil or upper regolith between North Ray and South Ray has not been completely homogenized since the time of formation of these craters.

3) The chemistry of the soil indicates that rocks rich in potassium, uranium, and thorium, similar to those that prevail at the Fra Mauro site, are relatively abundant (10 to 20 percent) in the Descartes region.

4) The K/U ratio of the lunar crust is similar to that of the KREEP basalts.

5) The carbon content of the premare lunar crust is even lower than that of the mare volcanic rocks.

References and Notes

1. D. A. Papanastassiou and G. J. Wasserburg, *Earth Planet. Sci. Lett.* **11**, 37 (1971); G. Turner, *ibid.*, p. 169; G. J. Wasserburg and D. A. Papanastassiou, *ibid.* **13**, 97 (1971); V. R. Murthy, N. M. Evenson, B. Jahn, M. R. Coscio, Jr., *Science* **175**, 419 (1972).
2. W. K. Hartman, *Icarus* **13**, 299 (1970).
3. N. J. Trask and J. F. McCauley, *Earth Planet. Sci. Lett.* **14**, 201 (1972).
4. C. A. Hodges, *Miscellaneous Geological Investigations Map I-748* (U.S. Geological Survey, Washington, D.C., 1972); D. E. Wilhelms and J. F. McCauley, *Miscellaneous Geological Investigations Map I-703* (U.S. Geological Survey, Washington, D.C., 1971).
5. F. Hörz, W. D. Carrier, J. W. Young, C. M. Duke, J. S. Nagle, R. Fryxell, in preparation.
6. C. Meyer, Jr., R. Brett, N. J. Hubbard, D. A. Morrison, D. S. McKay, F. K. Aitken, H. Takeda, E. Schonfeld, *Geochim. Cosmochim. Acta* **1** (Suppl. 2), 393 (1971); C. Meyer, Jr., Contribution 88, Lunar Science Institute (1972), p. 542.
7. Arabic numerals represent the order of presentation in this paper. Roman numerals were developed during the preliminary examination and have been retained because they appear in several documents circulated to principal investigators by the lunar sample curator.
8. W. Wahl, *Geochim. Cosmochim. Acta* **2**, 91 (1952).
9. Apollo 15 Preliminary Examination Team, *Science* **175**, 363 (1972).
10. N. J. Hubbard, J. M. Rhodes, P. W. Gast, B. M. Bansal, H. Wiesmann, S. E. Church, in preparation.
11. Lunar Sample Preliminary Examination Team, *Science* **167**, 1325 (1970); Lunar Sample Preliminary Team, *ibid.* **173**, 681 (1971).
12. C. B. Moore, E. K. Gibson, J. W. Larimer, C. F. Lewis, W. Nichiporuk, *Geochim. Cosmochim. Acta* **2** (Suppl. 1), 1375 (1970).